# EIC Detector R&D
# Progress Report FY18

**Project ID:** eRD3

**Project Name:** Design and assembly of fast and lightweight forward tracking prototype systems for an EIC

**Period Reported:** January 2018 – July 2018 (Status)

**Project Leaders**:
Professor Bernd Surrow and Dr. Matt Posik (Temple University) / Dr. Franck Sabatie (Saclay)

**Date:** June 27, 2018

**Applicant Address**: Temple University
Department of Physics
Science Education and Research Center
1925 North 12th Street
Philadelphia, PA, 19122

**Contact Persons:** Professor Bernd Surrow and Dr. Matt Posik

**Email:** surrow@temple.edu and posik@temple.edu

**Phone:** 215-204-7644

## Introduction

This report concentrates on a dedicated tracking system based on micro-pattern detectors, which focuses on the design and development of fast and lightweight detectors, ideally suited for a future EIC experiment. The science case and basic detector specifications have been documented in a White paper report [1]. The micro-pattern tracking detector system consists of:

- Barrel tracking system based on MicroMegas (MM) detectors manufactured as six cylindrical shell elements.
- Rear / Forward tracking system based on triple-GEM detectors manufactured as planar segments of three layers in the rear and forward directions.

An alternative layout for the MM barrel tracking system consists of a TPC together with one inner and outer fast radial MM layer to aid the actual TPC track reconstruction. This option has not been worked out in detail yet.

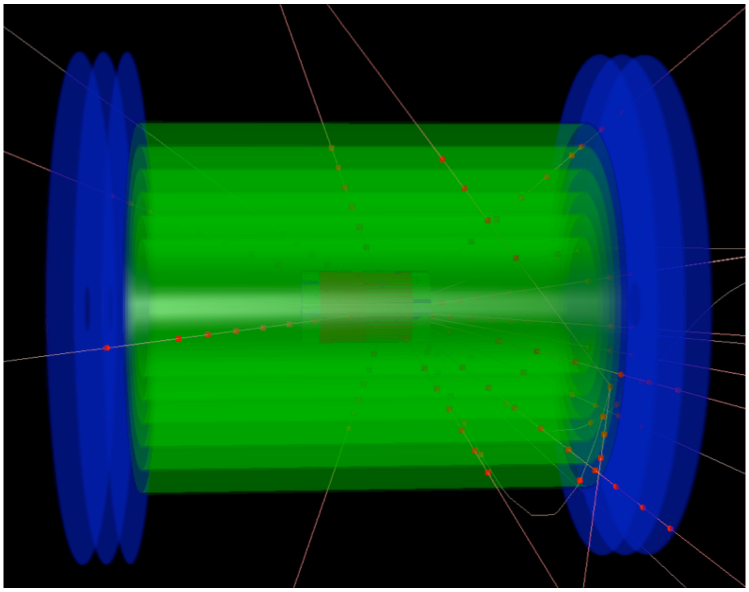
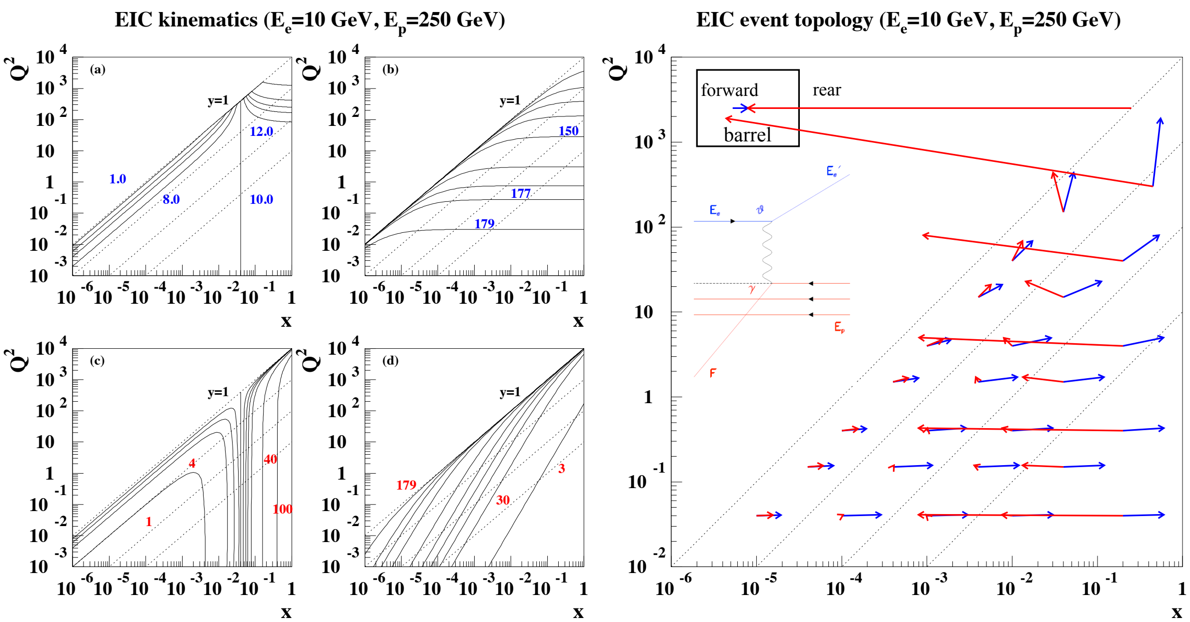


**Figure 1:** *GEANT simulation of barrel (green) and rear / forward (blue) tracking systems for an EIC detector.*

Figure 1 shows a 3D view of a GEANT simulation for a barrel and rear / forward tracking system which has been initiated by the R&D program documented in this report. The R&D effort focuses on the following areas:

- Design and assembly of large cylindrical MicroMegas detector elements and planar triple-GEM detectors,
- Test and characterization of MicroMegas and triple-GEM prototype detectors,

- Design and test of a new chip readout system employing the CLAS12 DREAM-chip development, ideally suited for micro-pattern detectors,
- Utilization of light-weight materials,
- Development and commercial fabrication of various critical detector elements and
- European/US collaborative effort on EIC detector development (CEA Saclay and Temple University).




$E_e/E_p = 0.04$

**Figure 2:** *EIC kinematics shown as isolines (left) and event topology (right) in the $Q^2$-x plane for 10 GeV (electron) on 250 GeV (proton) beams. Electron variables are shown in blue whereas proton / current-jet quantities are shown in red. The upper left box indicates the initial state configuration of 10 GeV (blue) on 250 GeV (red). The magnitude of each arrow is a reflection of the energy whereas the direction is the polar angle direction*

The basic kinematic requirements of ep physics will be summarized below. Using basic energy and momentum conservation in ep scattering, the ep event kinematics as shown in Figure 2 in terms of x (or y) and $Q^2$ can be characterized by the scattered electron in terms of its energy and polar angle or in terms of the struck quark giving rise to a current jet characterized by its respective energy and polar angle. All polar angles are measured with respect to the initial-state proton direction.

At low and moderate $Q^2$ and low x, both the current jet and the scattered electron have very low energy and are predominantly found in the rear direction. For fixed low and moderate $Q^2$ and increasing x values, the current jet is moving away from the rear direction into the barrel and eventually at high x in the forward direction. The rear direction is characterized by extremely small electron energies which is even more pronounced at smaller center-of-mass energies which is generally required for $F_L$-type measurements. Low dead material ( $\leq 1\,\%\,X_0$), a precision energy measurement ( $\leq 10\,\%/\sqrt{E}$) and precise hit localization ( $\leq 1$ mm) along with precision energy calibration ( $\leq 0.5\,\%$ ) and alignment ( $\leq 1$ mm) at a rear calorimeter system are critical. The requirements in the forward direction are less stringent due to the larger energies in the final state. This has been shown by both the H1 and ZEUS experiments at HERA which will become even more challenging at an EIC facility due to the smaller beam energies. All of those items turned out to be challenging aspects if not taken care of properly [2]. A triple-GEM forward and rear tracking system provides the needed precision hit localization directly in front of a rear and forward calorimeter system and aids in the understanding of pre-showering and dead material mapping. In the rear direction, a precision hit determination for scattered electrons is indispensable for precise $Q^2$ reconstruction and critical for probing ep collisions as a function of large to low $Q^2$. In the forward direction precise hit localization is critical for a) particle track/calorimeter mapping and b) required to enable hit points in front and behind the forward RICH detector system as featured in the JLEIC detector design[1].

This report provides an overview of various R&D activities in FY18. Dr. Matt Posik, besides his physics analysis efforts at the STAR experiment, are now shared between the College of Science and Technology at Temple University and the EIC R&D sub-contract(~15%). Dr. Amilkar Quintero has split his commitment between the EIC R&D program (~15%) and the physics analysis program of high-energy polarized p+p physics (~85%) with Professor Bernd Surrow at RHIC covered by his DOE Nuclear Physics base grant. The College of Science and Technology is strongly supporting the R&D program with both manpower and equipment support. Mr. James Wilhelmi, a mechanical engineer, provides dedicated support for Nuclear Physics research activities at Temple University. We do consider this and the local new machine shop an outstanding resource for our detector development work.

It should be emphasized the commercial GEM (eRD3) R&D program is a dedicated development, in particular to commercial development, of various elements for a future EIC tracking detector system. The commercial GEM (eRD3) R&D program is on track to be completed in 2019. It should be mentioned that eRD3 has now officially merged into eRD6. As such this is the last eRD3 progress report. All future projects and proposals will be made through the eRD6 consortium.

Over the last reporting period we have promoted our EIC R&D research efforts with a presentation based on the status of our R&D program at the Micro-Pattern Gas Detector (MPGD) 2017 conference [3]

The lack of funding for the MM part concerning the 2D development is a serious concern. It should be emphasized that the MM part is the only dedicated MM tracking system presented so far and currently provides the only alternative to a full TPC option.

---

[1] https://eic.jlab.org/wiki/index.php/Main_Page

The International Advisory Committee of the MPGD conference series selected Temple University to host the MPGD 2017[2] conference, together with a full-day RD51 collaboration meeting. This conference took place on May 22-26, 2017 at Temple University with about 100 participants from Asia, Europe and North and South America. We do consider the selection by the International Advisory Committee to host the International MPGD conference as a strong recognition of the EIC R&D program on an international level. It was stated during various overview presentations that the US MPGD community is centered around the EIC R&D program.

## Forward Triple-GEM R&D Program: Progress Report

**What was planned for this period?**

Over the time period of January - June 2018, we had planned to carry out research in several areas:

1. Construction of several 40 cm x 40cm triple-GEM tracking detectors using commercial single-mask GEM foils, HV foils, and readout foils all produced by Tech-Etch. These detectors will allow us to study and compare the GEM quality of a commercial foil to that of the well established CERN foils. These prototype triple-GEM detectors also allow us to investigate replacing the standard G10 spacer grids, which sit between GEM foil layers in a triple-GEM detector to keep the layers from sagging and touching, with thin Kapton spacer rings. The Kapton spacer rings present the potential to reduce both cost and dead material compared to the more conventional spacer grids.

2. Continue serving the MPGD community using our CCD GEM scanner.

3. Design of a radiation enclosure to operate a 50-keV X-ray tube, which is needed for triple-GEM detector gain and efficiency measurements.

**What was achieved?**

1. CCD GEM Scanner

A CCD GEM scanner allows one to image and optically analyze the geometrical properties of GEM foils, such as the GEM hole pitch, inner hole and outer hole diameters. These properties can be used, in addition to electrical leakage current tests, to determine the foils overall quality.

We have now completed optical scans of all twelve Tech-Etch single mask foils that Temple University had received. However, even with the completion of the Tech-Etch foil analysis, the CCD GEM scanner is still getting a lot of use from the EIC R&D and MPGD communities. As

[2] MPGD2017 WWW-page: https://phys.cst.temple.edu/mpgd2017/

reported in the last progress report we had scanned for FIT an EIC prototype GEM foil, developed between eRD3 and eRD6, that was produced by CERN and for UVa a CERN produced Cr-GEM. Additionally we have recently scanned a couple foils for the BONUS experiment and recently received a CMS foil that is being developed by the company Mecaro as an alternative to CERN foils. These examples emphasis the important role that the GEM CCD scanner plays and will continue to play for the MPGD community as a whole.

**BONUS GEM Scans**

We have recently finished scans of a couple GEM foils from the BONUS experiment. This foils are ~20 cm x 17 cm, and were produced by Tech-Etch via double-mask technique. The BONUS experiment saw some gain variations their data and wanted see if it could be related to the geometry of the GEM foil. The GEM foil scans show acceptable geometric quantities for the pitch, inner hole, outer hole diameters, and the deviation of the inner hole diameter from the mean, shown in Fig. 3. Similar results were found for both foils that were scanned and can be concluded that the gain variation most likely was not a result of the GEM foil geometry.

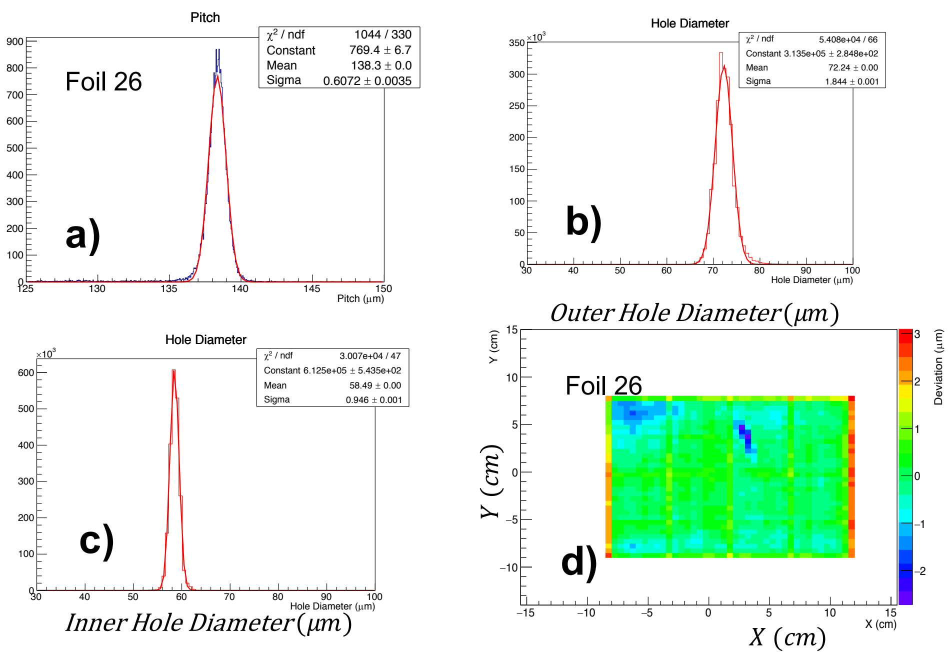



**Figure 3***: Scan results of a BONUS GEM foil. a) Hole pitch distribution. b) Outer hole distribution. c) inner hole distribution. d) Inner hole diameter deviation from mean.*

**Mecaro GEM**

Mecaro is a Korean company working with CERN to develop large GEM foils for the CMS upgrade. These foils are roughly 100 cm x 60 cm and produced via the double-mask technique. A test foil has recently been sent to Temple University for optical analysis. We are also going to use this opportunity to train one of the new graduate students, Babu Pokhrel, on CCD GEM scanning. Figure 4 shows Babu Pokhrel scanning the Mecaro GEM.

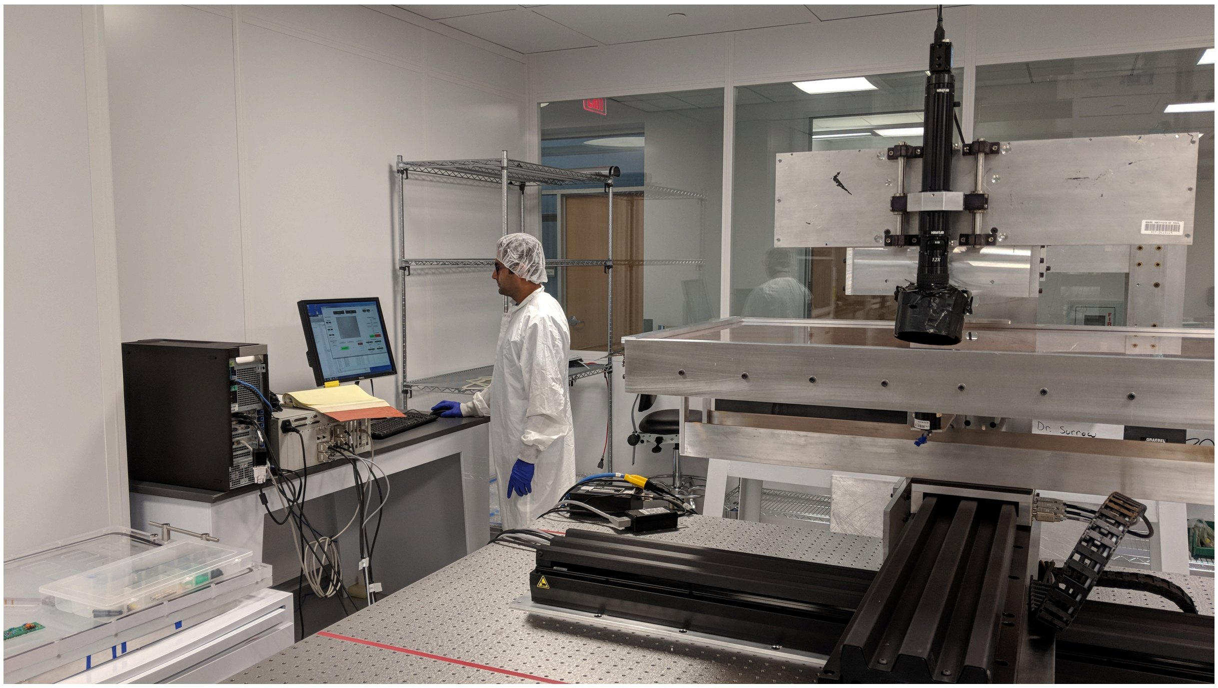


**Figure 4***: Scanning of Mecaro foil by new graduate student.*

2. <u>40 cm x 40 cm Prototype triple-GEM Detectors</u>

The prototype triple-GEM detectors, built using Tech-Etch foils, are based on the STAR FGT design [4]. The FGT design was chosen to save both money and time. Temple University already has all of the tooling specific to the FGT design that is needed to build a triple-GEM detector. This includes a nitrogen enclosure for leakage current testing, a stretching jig for gluing the foils and frames, a design for the HV foil, frame design, readout board design, and soldering station. Those items are all located inside our MPGD clean room facility.

At the time of the previous report we had assembled two triple-GEM detectors. Both use Tech-Etch produced single mask foils, HV foils, and readout foils. The only difference between the two detectors is that one was built using the Kapton spacer rings, while the other used the more conventional G10 spacer grids. Figure 5 shows the layer of Kapton spacer rings (a) and G10 spacer grids (c) being inserted to separate two GEM foils. Figure 8b and 8d, show the completed assembley of the two detectors using Kapton rings and spacer grids, respectively, to separate the foil layers.

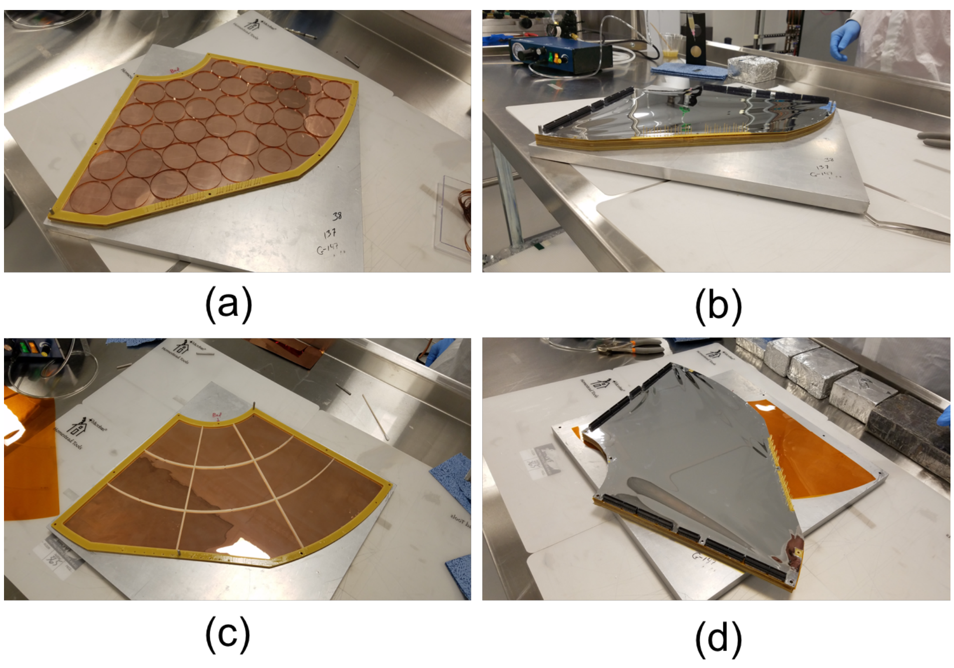



**Figure 5**: *Two triple-GEM detectors using Tech-Etch foils. (a) shows the application of the Kapton spacer rings, (b) completed triple-GEM detector using the Kapton spacer rings, (c) shows the application of the G10 spacer grids, and (d) shows the completed triple-GEM detector using the G10 spacer grids.*

Initial electrical tests of the triple-GEM detector built with the Kapton spacer rings were measured to be near the 1 nA or less level. This included leakage current measurements of each of the nine sectors for all three GEM foil layers at 500 V under N2 flow. The triple-GEM detector was then connected to the STAR DAQ setup in Temple University's detector lab, where a voltage of about 3 kV was applied to the triple-GEM detector and its current was monitored for about 1.5 days to see if there was any noticeable charge-up effects. After 1.5 days, no evidence of charging-up was seen. We also compared the two prototype GEM detectors to several STAR FGT triple-GEM detectors (those used in the actual STAR FGT), where we noticed that the prototype GEM detectors were drawing a current that is roughly a factor of 1.5 times higher than the STAR FGT quadrants. Despite this larger current, it seemed as though the prototype detectors were functioning satisfactory as we were seeing some cosmic events while running through some initial optimizations. However the detectors began to deteriorate rather quickly. When pulling the detectors out of the cosmic ray stand and studying them, we saw that the initial prototype detector we inserted (Kapton rings) into the STAR FGT has shorts at nearly all GEM HV sectors, and the detector would no longer function. The other prototype detector (G10 rings) had the HV turned off soon enough that only 2 of the sectors are dead. We have tested the HV boards used in each of the prototype detectors and have determined that they were not the cause of the detector failures. We are planning on opening the prototype detector with the Kapton rings to see if we can determine what caused the initial shorting.

We are now building a third prototype implementing the experience learned from building the first two detectors, with particular care during soldering HV connectors and removing unused connector pads, to minimize any potential future shorts.

While we are building the third prototype detector, Dr. Amilkar Quintero has begun training three new graduate students on how to take and analyze data on the STAR DAQ. Figure 6 shows the three graduate students, Santos Neupane and K.C Biru, working in the Temple detector lab. They will be optimizing the DAQ and FGT detector to take cosmic data, and characterize the three best STAR FGT quadrants using cosmic. These results will serve two purposes in this EIC R&D. First the STAR FGT cosmic mapping will serve as a reference to the Tech-Etch prototype triple-GEM detectors. Secondly, the STAR FGT quadrants will be used to try and extract a tracking efficiency from the prototype detectors.

**Figure 6:** *Two graduate students working in the Temple detector lab.*

**What was not achieved, why not, and what will be done to correct?**

The design of the radiation enclosure is in progress.

**What is planned for the coming months and beyond? How, if at all, is this planning different from the original plan?**

In the upcoming months our efforts will be focused on finishing out our already proposed commercial triple-GEM R&D. This includes cosmic ray and 55Fe testing of the prototype triple-GEM detectors built using Tech-Etch GEM, HV, and readout foils. As well as comparing the results of the prototype detectors, to those used in the STAR FGT. Additionally, we also plan to complete the x-ray enclosure, needed to operate our high rate x-ray gun.

## Barrel MicroMegas R&D Program

### Past

**What was planned for this period?**

In FY16 / FY17, we had planned to carry out R&D efforts on the DREAM chip application to GEM detectors and 2D curved resistive MicroMegas prototype detectors: this technology has the clear advantage of minimizing the amount of material with respect to two 1D detectors.

**What was achieved?**

In 2016, the Saclay group was able to successfully design, build and test a transition card to connect a FGT quarter section triple-GEM detector to their current DREAM front-end-electronics. To connect the FGT to the DREAM electronics, a passive transition card was built to connect the

2 “super-connectors” of one FGT quarter section to the MEC8 connectors used with the DREAM front end electronics. This FGT-DREAM card replaces the FGT-APV cards and allows the detector to readout using the DREAM chips rather than the APV chips. In addition to the GEM readout electronics work, the Saclay group has also continued further cosmic ray testing of their 1D MicroMegas barrel detector.

**What was not achieved, why not, and what will be done to correct?**

The lack of R&D funding delayed the process of the 2D Micro-meags R&D work.

## External Funding

Temple University and Saclay did not receive any other grant funding in support of the actual R&D program discussed here. However, it should be emphasized that Temple University provided substantial facility support and the support of manpower such as a mechanical engineer at Temple University.

## Manpower

Dr. Amilkar Quintero  and Dr. Matt Posik both contributed 0.15 FTE each to this project.

## List of eRD3 Publications

1. M. Posik and B. Surrow, MPGD 2017 Proceedings, arXiv:1806.01892 (2018).

2. M. Posik and B. Surrow, Conference Record to IEEE Nucl. Sci. Symposium, (2016) [arXiv:1612.03776].

3. M. Posik and B. Surrow, Nucl. Instrum. Meth. A 802, (2015) 10.

4. M. Posik and B. Surrow, Conference Record to IEEE Nucl. Sci. Symposium, (2015) [arXiv:1511.08693].

5. Zhang et al., Conference Record to IEEE Nucl. Sci. Symposium, (2015) [arXiv: 1511.07913].

## References

[1] A. Accardi et al., Report on ‘Electron Ion Collider: The Next QCD Frontier-Understanding the glue that binds us all’, arXiv 1212.1701 (2012).

[2] B. Surrow, Eur. Phys. J. direct 1, no. 1, 2 (1999).

[3] M. Posik and B. Surrow, MPGD 2017 Proceedings, arXiv:1806.01892 (2018).

[4] B. Surrow, Nucl. Instrum. Meth. A 617, (2010) 196.